Species detection framework using automated recording units: a case study of the Critically Endangered Jerdon's courser

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Abstract With the advent of automated recording units, bioacoustic monitoring has become a popular tool for the collection of long-term data across extensive landscapes. Such methods involve two main components: hardware for audio data acquisition and software for analysis. In the acoustic monitoring of threatened species, a species-specific framework is often essential. Jerdon's courser *Rhinoptilus bitorquatus* is a Critically Endangered nocturnal bird endemic to a small region of the Eastern Ghats of India, last reported in 2008. Here we describe a reproducible and scalable acoustic detection framework for the species, comparing several commonly available hardware and detection methods and using existing software. We tested this protocol by collecting 24,349 h of data during 5 months. We analysed the data with two commercially available sound analysis programmes, following an analysis pipeline created for this species. Although we did not detect vocalizations of Jerdon's courser, this study provides a framework using a combination of hardware and software for future research that other conservation practitioners can implement. Vocal mimicry can aid or confound in detection and we highlight the potential role of mimicry in the detection of such threatened species. This species-specific acoustic detection framework can be scaled and tailored to monitor other species.

Keywords Automated recording units, Critically Endangered, detection framework, Eastern Ghats, India, Jerdon's courser, passive acoustic monitoring, *Rhinoptilus bitorquatus*

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Introduction

Monitoring techniques are crucial for the conservation of species. Many field-based monitoring techniques, such as point counts, mist-netting and transect surveys (Ralph et al., 1995; Dunn & Ralph, 2004) are labour- and expertise-intensive, but the use of passive acoustic monitoring with automated recording units is gaining momentum (Teixeira et al., 2019) for monitoring a variety of taxa. Recorders can be programmed and deployed for long periods without human intervention, ensuring high research productivity (Shonfield & Bayne, 2017). The acoustic signals of many species can be detected at greater distances than visual cues because they have evolved for use in breeding, foraging and alarm calling (Laiolo, 2010), and with species-specific acoustic signatures passive acoustic monitoring can be ideal for monitoring many species (Brandes, 2008).

Automated recording units have been used for monitoring several threatened bird species (Williams et al., 2018; Dema et al., 2020; Leseberg et al., 2020; Vu & Van Tran, 2020), in particular cryptic birds (Frommolt & Tauchert, 2014; Zwart et al., 2014; Bobay et al., 2018; Pérez-Granados et al., 2018) and those that call infrequently (Goyette et al., 2011). The success of passive acoustic monitoring primarily involves a robust combination of hardware (recorders) and detection software, often specific to a species–habitat configuration. In this study we used automated recording units to create a replicable detection framework for the Critically Endangered Jerdon's courser *Rhinoptilus bitorquatus*, a nocturnal and cryptic bird, endemic to the Eastern Ghats of India (BirdLife International, 2017).

Hardware considerations are critical for passive acoustic monitoring. This includes considerations of the recording radius of automated recording units, microphone sensitivity (Darras et al., 2019) and the nature of the habitat (Pérez-Granados et al., 2019). It is also essential to have custom-built acoustic algorithms to detect the calls of the target species (Knight et al., 2017) and reject vocalizations of co-occurring species (Priyadarshani et al., 2018). This is particularly useful when there are many hours of recordings and it is impractical to examine them manually. Thus a species- and habitat-specific monitoring framework is required, especially for conservation purposes.

Jerdon's courser is one of the rarest birds (BirdLife International, 2017). After being considered extinct, without
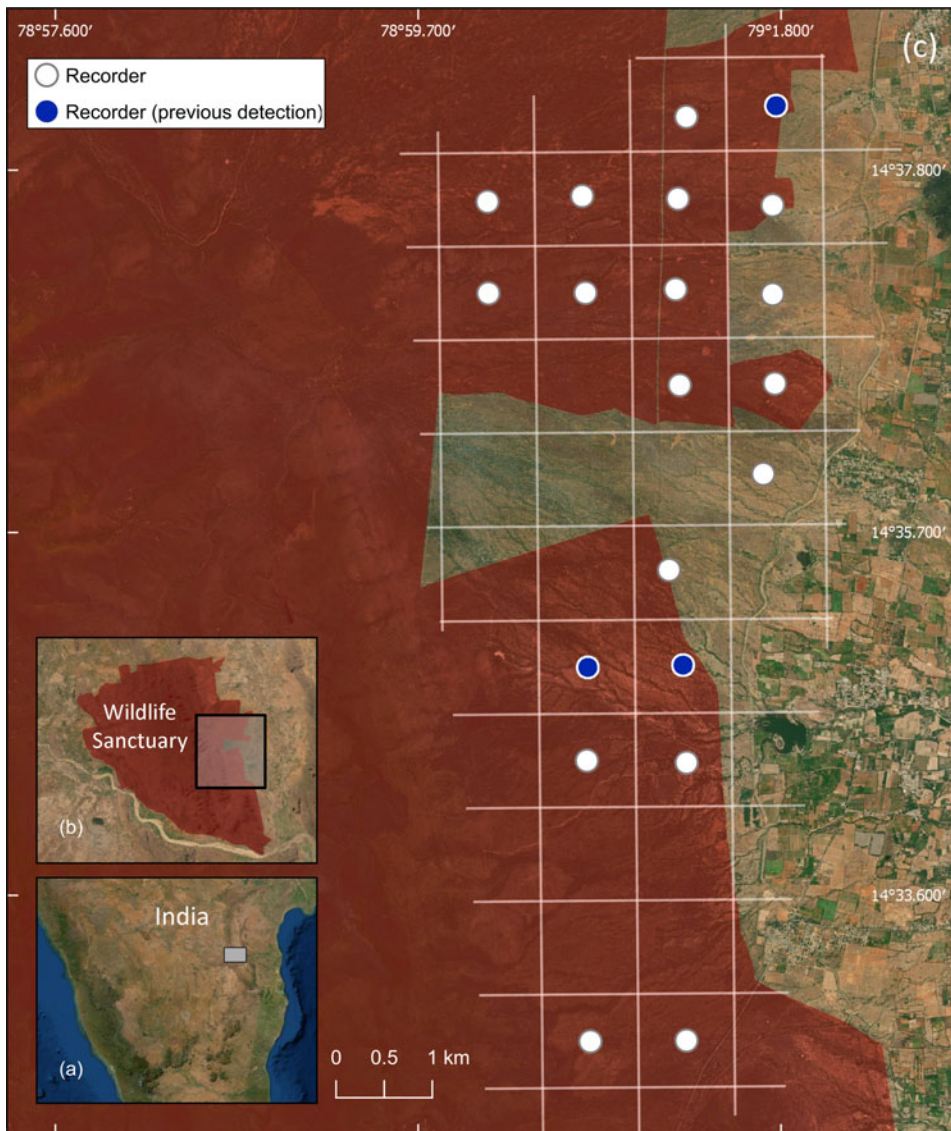
Fig. 1 (a) The location of Sri Lankamalleswara Wildlife Sanctuary in India, (b) the location of the study area, and (c) the 1 × 1 km grid, indicating those grid cells in which we placed recorders and those where Jerdon's courser *Rhinoptilus bitorquatus* had been previously detected.

sightings since 1900, it was rediscovered in 1986 (Bhushan, 1986) but has not been detected since 2008. Jerdon's courser prefers a type of scrub forest that is under great anthropogenic pressure (Jeganathan et al., 2008). The species was previously detected using labour-intensive methods such as night searches (Bhushan, 1994), tracking strips and camera traps (Jeganathan et al., 2002). The detection methods used involved listening for spontaneous calls in places where Jerdon's courser is known to have occurred, and walking transects while listening for calls in response to playback of the species' calls. But the rate of spontaneous calls and the response rate to call playback was poor (Jeganathan, 2006). So far, Jerdon's courser has been recorded only in a small area of scrubland in the Sri Lankamalleswara Wildlife Sanctuary. Because of its Critically Endangered status and highly restricted range, we conducted this study to develop a site-specific detection framework using automated recording units and sound

analysis software. We did this first by testing potentially suitable commercially available recorders, and then by creating and testing a call detection analysis pipeline using two commonly available sound analysis programmes. For the latter, we provide a flowchart to validate detections.

Study area

We conducted this study in the 464 km² Sri Lankamalleswara Wildlife Sanctuary in Andhra Pradesh, India, which comprises scrubland type habitat considered suitable for Jerdon's courser (Jeganathan et al., 2004; Fig. 1).

Methods

Call characteristics

Jerdon's courser has only one known call type, a di-syllabic kwick-koo repeated in a series (Jeganathan & Wotton,
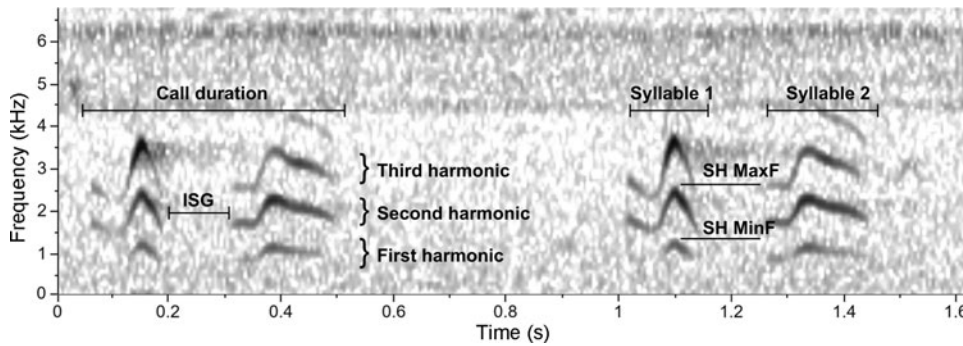
FIG. 2 The call of Jerdon's courser has two parts, Syllable 1 and Syllable 2, separated by an inter-syllable gap (ISG). The call duration comprises the two syllables and the inter-syllable gap. The spectral properties consist of a fundamental note at the lowest frequency followed by second and third harmonics above. The maximum (SH MaxF) and minimum frequency (SH MinF) of the second harmonic are indicated.

2004). The only known recordings of Jerdon's courser were obtained by PJ on 11 occasions during June 2001–November 2002, at dusk, from the Wildlife Sanctuary (Fig. 1). The calls were recorded from three locations, most likely from multiple individuals, at a distance of 10–100 m from the birds. These calls were recorded using analogue tapes and converted to digital format by the Macaulay Library, Cornell University (accession numbers 274533–43).

To check for variability in Jerdon's courser calls, we analysed 145 clear di-syllabic calls from the 312 calls available in the recordings (faint calls were excluded). The call has a fundamental note at the lowest frequency between mean $654.55 \pm SD$ 54.68 Hz and highest frequency between mean $1,238.05 \pm SD$ 56.48 Hz with two visible harmonics above this (Fig. 2). The second harmonic appears to have the highest energy and can be heard at the farthest distance (see attenuation experiment below). The mean call duration is $0.4667 \pm SD$ 0.042 s with a mean inter-syllable-gap of $0.090 \pm SD$ 0.027 s (Fig. 2). A spectral cross-correlation matrix was created for each of the two syllables using the *batch correlator* function in *Raven Pro 2.0 beta* (Center for Conservation Bioacoustics, Cornell University, Ithaca, USA). Normalized spectral cross-correlation values range from 0, denoting least similarity, to 1, denoting the maximum possible similarity between two notes (Charif et al., 2010).

Field protocol

Attenuation experiment We conducted an attenuation experiment using Jerdon's courser playback calls to determine the grid size for the deployment of the recorders (Supplementary Material 1, Supplementary Fig. 1). We used four types of commercial recorders: SongMeter4 (Wildlife Acoustics, Maynard, USA), Swift (Cornell Center for Conservation Bioacoustics, Cornell University, Ithaca, USA), Rugged Swift (modified Swift in a Pelican casing, Torrance, USA), and AudioMoth (Open Acoustics, Eastleigh, UK). We detected the call at up to 700 m, using all recorders, and conservatively fixed the field sampling grid cell size at 1×1 km.

Deployment We created a grid of 1×1 km cells along the eastern boundary of the Sanctuary using a preliminary habitat suitability map (Jeganathan, 2006). We deployed 17 recorders (Swift, Rugged Swift and SongMeter4), one at the centre of each selected grid cell, and included all locations where Jerdon's courser had previously been recorded. We conducted four recording cycles (c. 30 days each, after which batteries in all recorders were replaced) during November 2019–March 2020 as the bird is thought to be most vocal during this period (Jeganathan & Wotton, 2004). All recorders were randomly distributed across the grid. We deployed two AudioMoth recorders on the same tree as other recorders, for further testing (Supplementary Table 1); data from these were not used in the analysis (but see below). As Jerdon's courser is known to vocalize within an hour after sunset (Jeganathan, 2006), we recorded continuously during 17.00–06.00 (with a 48,000 Hz sampling rate, in wav format) on 17 recorders × 4 cycles, giving 68 recording instances (one recording instance is c. 290 h of data collected from one recorder per battery cycle). We also analysed an additional dataset of 83 h from an AudioMoth recorder that malfunctioned and recorded only daytime calls.

Call detection analysis pipeline

Creating a recognizer A recognizer is an algorithm to detect a single specific category of sounds. Recognizers can operate either via two steps (first detect a broad range of sounds, then classify those) or in a single step (only detect sounds that match a template) (Knight et al, 2017). To build a detector (an algorithm to detect sounds of potential interest in a continuous recording), we considered only the frequency band of the second harmonic of the call, which ranges from a mean minimum of $1307.25 \pm SD$ 76.68 Hz to a mean maximum of $2375.65 \pm SD$ 89.89 Hz (Fig. 2). We chose the second harmonic as the first and third harmonic attenuated faster at increasing distances

from the source (Supplementary Fig. 1). For the call detection we created an analysis pipeline with *Raven Pro* and *Kaleidoscope* (Wildlife Acoustics, 2019).

In *Raven Pro* the template detector function works on the principle of spectrogram cross-correlation (Ulloa et al., 2016). Calls most similar to the template are detected based on a given threshold cut-off (Knight et al., 2017) and use certain specific spectrogram parameters (Hann spectrogram window = 512 samples, discrete Fourier transform size = 512, hop size = 256 samples, grid spacing = 93.8 Hz, overlap = 50%). For *Raven Pro* we chose two clear and loud FoxPro Predator speaker (FOXPRO, Lewistown, USA) playback (from our attenuation experiment) di-syllabic Jerdon's courser calls as a template and used a selection around each syllable as an independent template, resulting in four templates. We chose the playback version as the signal-to-noise ratio was better in the playback call and it was recorded on an automated recording unit. The templates were used in the template detector function of *Raven Pro* on a training dataset of 160 Jerdon's courser calls. The template detector settings (frequency range = ± 5 Hz, threshold value = 0.55) were set to maximize the number of true positives.

In *Kaleidoscope,* detection of target species works on K-means clustering using the hidden Markov model in which similar sounds are clustered together (Pérez-Granados & Schuchmann, 2020). In the first step, we conducted a basic cluster analysis on a training dataset containing 119 Jerdon's courser di-syllabic calls and calls of co-occurring species (common hawk-cuckoo *Hierococcyx varius* and Jerdon's nightjar *Caprimulgus atripennis*, using the co-occurring species-elimination flowchart, as explained below). We used particular settings (fast Fourier transform size = 512, maximum distance from cluster centre = 0.1, maximum states = 12, maximum distance to cluster centre = 0.5 and maximum clusters = 10) and fixed signal detection parameters (frequency band = 1,500–2,300 Hz, detection length = 0.05–0.1 s, inter-syllable gap = 0.35 s) that resulted in clusters of the target Jerdon's courser calls and non-target calls of the co-occurring species. Calls were then manually annotated and the resulting file was used as a template to rescan the training data via a second round of cluster analysis. The second round of clusters was then manually re-validated and re-annotated to create the recognizer.

Assessing the performance of the recognizer   The efficacy of the recognizers created with *Raven Pro* and *Kaleidoscope* were evaluated on a test dataset by calculating three performance metrics (Knight et al., 2017; Priyadarshani et al., 2018):

$$Precision = \frac{true\ positives}{true\ positives + false\ positives}$$

$$Recall = \frac{true\ positives}{true\ positives + false\ negatives}$$

$$F_{beta}\ score = (1 + \beta)\frac{precision \times recall}{(\beta^2 \times precision) + recall}$$

An F_{beta} score balances precision and recall. As the target species is a rare bird with an infrequent calling pattern, we wanted to minimize the false negatives and therefore set the β value = 2, to prioritize recall (Knight et al., 2017). We created a synthetic test dataset using 10 h of recordings overlaid with 415 di-syllabic Jerdon's courser calls (from Macaulay Library (Cornell University, accession numbers 274533–43) and our FoxPro playback from our attenuation experiments, as described in Supplementary Material 1).

Screening automated recording unit data   To segregate calls of Jerdon's courser from those of co-occurring species, we used a species elimination flowchart (Fig. 3) that included using eBird (2021) checklists for the region and our software recognizer. In the first step, we obtained from eBird an up-to-date list of all bird species present in Sri Lankamalleswara Wildlife Sanctuary and segregated species that vocalized within the call frequency band of Jerdon's courser. We then used the *Raven Pro* and *Kaleidoscope* recognizers to screen the collected recorder data with our recognizers. All detections were manually cross-checked both visually and aurally (by VJ and CA) with species' calls from the eBird shortlist. Detected calls were compared with recordings of shortlisted species available on eBird and Xeno-canto (Xeno-canto, 2021). In the case of unclear detections, spectrogram audio segments of 60 s before and after the detections (to examine the context of the occurrence of the call) were taken into consideration to identify the species (by PJ and VJ). Detections were categorized into known and unknown bird species. The unknown calls were sent to 11 experts in bird acoustics who are familiar with the calls of birds of this region or South India, in the form of a questionnaire for species identification. The questionnaire consisted of videos of a moving spectrogram of the unknown calls (Supplementary Material 2). The experts were asked to rate each call on a five-point Likert scale that ranged from being least likely to most likely to belong to Jerdon's courser. For the calls identified as most likely to belong to Jerdon's courser, a spectral cross-correlation was performed in *Raven Pro* to quantify the similarity between the detected call and the known Jerdon's courser di-syllabic call.

Results

Performance metrics of the recognizers

The *Raven Pro* recognizer gave us the best results on the test dataset, with precision = 0.341, recall = 0.490 and F_{beta}
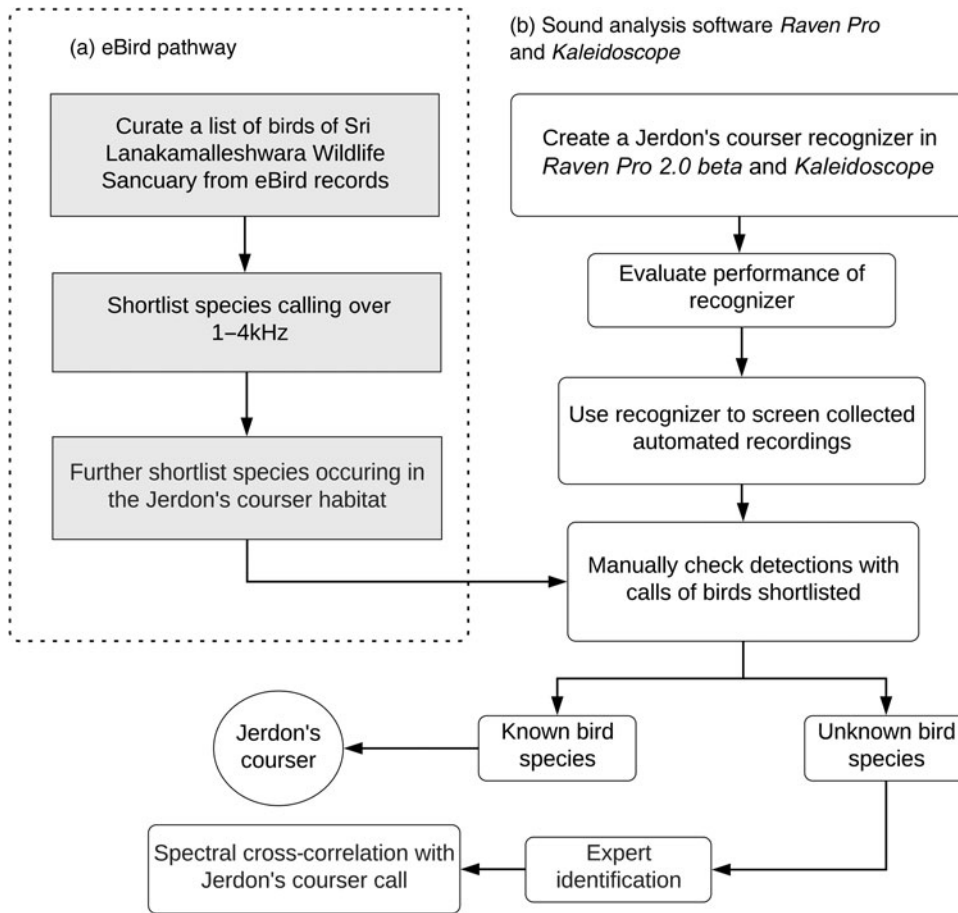
FIG. 3 Our analysis pipeline, showing the species elimination pathways for any putative calls of Jerdon's courser using (a) a database of species calling within the Jerdon's courser call band in Sri Lankamalleswara Wildlife Sanctuary, and (b) the detection algorithms in *Raven Pro 2.0 beta* and *Kaleidoscope*. We used known Jerdon's courser calls to create a recognizer in *Raven Pro* and *Kaleidoscope* to screen automated recordings. The resulting detections were then manually verified and categorized into known and unknown bird species based on the shortlist of species from (a). Unknown calls were then sent to 11 experts for identification. We subsequently performed a spectral cross-correlation between the calls tagged as most likely belonging to Jerdon's courser and the actual call of Jerdon's courser, to check for similarity.

score = 0.451. The recognizer created with *Kaleidoscope* resulted in precision = 0.116, recall = 0.340 and F_{beta} score = 0.245. Higher recall values indicate fewer false negatives. In our F_{beta} score, the β values are set to favour recall over precision and higher scores indicate a greater minimization of false negatives.

Detection of Jerdon's courser call

We obtained 24,432 h of recordings. Data from four recording instances, three from the first recording cycle and one from the second cycle, were not available as a result of hardware technical issues.

In these recordings we detected 2,384,404 putative Jerdon's courser calls with *Raven Pro*, and 5,167,561 with *Kaleidoscope*. The majority of false positives were of co-occurring species that vocalize in the same bandwidth as Jerdon's courser (Supplementary Table 2), including the common hawk-cuckoo, Jerdon's nightjar and the Indian nightjar *Caprimulgus asiaticus*, which were segregated using our species elimination analysis pipeline (Fig. 3). We did not detect any Jerdon's courser di-syllabic vocalizations that unambiguously matched the known vocalization.

However, we shortlisted four calls that were similar to that of Jerdon's courser (Supplementary Fig. 2) and presented these to the 11 experts. One of these calls was identified as most likely to belong to Jerdon's courser by eight of the 11 experts. To check for similarity in spectral features of this call with that of Jerdon's courser we calculated spectral cross-correlation coefficients (Supplementary Table 3). We found that the first note of this call and that of Jerdon's courser had the highest similarity (cross-correlation score = 0.591), and note three of this call was most similar to note two of Jerdon's courser (cross-correlation score = 0.534). Both cross-correlation scores were within the range of the cross-correlation scores among PJ's field recordings of Jerdon's courser.

The context of this call was further examined manually by screening 1 h of recordings before and after the call. This call was recorded accidentally (as a result of incorrectly synchronized recorder clock settings), which resulted in recordings during the day (at 09.30) rather than at night. We found calls of other species (bay-backed shrike *Lanius vittatus*, Indian thick-knee *Burhinus indicus* and red-vented bulbul *Pycnonotus cafer*) in close succession to this putative Jerdon's courser call (Supplementary Fig. 3). The full call of Jerdon's courser was not detected

in this recording, and we believe the call was potentially a series of mimicked calls by the bay-backed shrike (discussed below).

Discussion

We used bioacoustics to create a detection framework to monitor the Critically Endangered, cryptic Jerdon's courser, the last confirmed occurrence of which was in 2008. The framework comprised a field protocol using automated recording units and an analysis protocol using two brands of sound analysis software.

Recommended field protocol

We found the Rugged Swift recorders to be the most suitable for long deployments (> 2 months on a 13-h nocturnal recording schedule). This is because they can hold 12 D-cell batteries, whereas the other tested recorders can carry only up to four D-cell batteries (Supplementary Table 1). Although we did not detect Jerdon's courser, we recommend retaining the grid size of 1×1 km for recorder deployment, based on our attenuation study, and expanding the sampling to surrounding viable habitats for this species (Supplementary Fig. 4). Differences in vegetation cover and wind direction can cause differences in attenuation properties (Yip et al., 2017; Thomas et al., 2020) and may contribute to the limitations of our study as a result of variability in the amplitude of natural calls. There could be differences between attenuation of calls from a live bird and that of playback calls; however, recording on a grid should detect the species given that it is likely to range across multiple grid cells.

Recommended software protocol

Both *Raven Pro* and *Kaleidoscope* have been used previously to create recognizers, with variable success rates (Knight et al., 2017). Their user-friendly interface does not require any prior programming knowledge, making it accessible to conservation management agencies and non-technical personnel. Our comparison of simulated data indicated that the recognizer created with *Raven Pro* performed better, with a higher F_{beta} score and a higher recall. This is similar to comparisons for other species (Knight et al., 2017). The stereotypic short calls of Jerdon's courser appear to be more efficiently detected with spectrogram cross-correlation methods used by *Raven Pro* (Ulloa et al., 2016) compared to the *K*-mean clustering method used by *Kaleidoscope* (Joshi et al., 2017).

Previous studies have also observed variable performance between manual and automated recognizers (Swiston & Mennill, 2009; Digby et al., 2013; Sidie-Slettedahl et al., 2015). The choice of method appears to depend on the target species (Joshi et al., 2017). In an automated approach, the most common challenges are the high number of false positives as a result of weak signals (Joshi et al., 2017), the absence of a good initial template, and any similar-sounding sympatric species (Schroeder & McRae, 2020). In our study, although the number of false positives was high, following a systematic analysis pipeline (Fig. 3) greatly reduced the manual screening time and was less time-consuming than screening the entire set of audio files, as also reported by Schroeder & McRae (2020). Automated classification approaches such as random forests (Ross & Allen, 2014) can sometimes reduce the number of false positives that need to be manually reviewed but we did not examine this possibility.

We detected one call that both our analysis and experts indicated was similar to that of Jerdon's courser. However, we considered the following additional points: (1) the putative call was during the day, (2) calls of the bay-backed shrike (a known mimic) were recorded at a similar time as the putative call, (3) there were also calls of multiple species in close succession to the putative call with similar amplitudes, (4) there was no other instance of the putative call in the sequence, and (5) the notes of the putative call had some degree of similarity in their spectral cross-correlation scores compared to those of the Jerdon's courser call yet they were not identical (potentially a modification of the call by the mimic of the model; Zollinger & Suthers, 2004). Jerdon's courser is nocturnal and calls were previously heard or recorded only during the night and on a few occasions at dusk. Their calls are also repetitive, with multiple calls in rapid succession. We believe therefore that the putative call is likely to be mimicry of a Jerdon's courser call by a bay-backed shrike, a known mimic (Yosef et al., 2020). Mimics can often sound similar to the model in acoustic characteristics, and are difficult to discern without context (Agnihotri et al., 2014). In the absence of additional recordings, it is difficult to assess definitively whether the detected call was of Jerdon's courser or of a mimic. Nevertheless, any mimicry would indicate exposure of the mimic to the model, either directly or culturally. Although mimicry can confound detections (Crisoglo et al., 2017), in the case of an endemic bird with a restricted range mimicry can be a clue for its detection. The presence of Jerdon's courser in this location cannot therefore be either confirmed or ruled out without more extensive year-round automated recording.

Our attempt to detect Jerdon's courser was based on the premise that it has only one call. Additional information on the call diversity of the species would potentially improve the ability to detect it. The most conclusive evidence for the occurrence of Jerdon's courser comes from camera traps (Jeganathan et al., 2002), which could be used to narrow down the location where the species occurs following any detection with automatic recording units. Although a comparison of the probability of detection with camera traps and acoustic recorders cannot be made without

additional information, acoustic recorders typically have much larger detection areas than cameras (unless the species has a very low-amplitude call).

Our species-specific acoustic detection framework could be scaled up and implemented by conservation agencies for the detection and long-term monitoring of this Critically Endangered bird. Knowledge of the local bird community is important for such research, as behaviours such as mimicry by other species need to be considered. Local enthusiasm for the conservation of Jerdon's courser appears to be high, as local newspaper reports erroneously carried stories that the species was detected (Supplementary Fig. 5), based on our study. We recommend an expanded acoustic survey for the species across all potentially suitable habitats. The acoustic monitoring protocols described here could be adapted to monitor other threatened, cryptic species whose vocalizations have been previously recorded.

Author contributions Conceptualization and design: CA, VJ, PJ, VVR; data collection and analysis: CA, VJ, with input from RC, PJ, VVR; writing: CA, with input from all other authors.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

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Species detection framework using automated recording units: a case study of the Critically Endangered Jerdon's courser

CHITI ARVIND, VIRAL JOSHI, RUSSELL CHARIF, PANCHAPAKESAN JEGANATHAN and V. V. ROBIN

SUPPLEMENTARY MATERIAL 1 Attenuation experiment to determine grid size for recorder deployment.

To determine grid size for deploying recorders we carried out a call playback attenuation experiment following (Yip *et al.,* 2017) at Sri Lankamaleswara Wildlife Sanctuary, the original habitat of the Jerdon's courser and at comparable habitat near Yerpedu (13° 41' 37.32" N, 79° 35' 38.4" E) which was also suggested as a potential Jerdon's courser site by Bhushan (1994).

To determine the amplitude of the call without any previous reference, we tested the volume for playback using a FoxPro Predator speaker (FOXPRO Inc. at different volumes and distances, from an observer (PJ) who has heard Jerdon's courser vocalisations on the field, following Darras *et al.* (2018). The FoxPro speaker is thought to reproduce animal sounds very accurately (MacLaren *et al.* 2018) and the volume of 20 points on this device (arbitrary volume scale for a specific recording) was auditorily verified as the approximate amplitude of the call . When measured with a Sound Level Meter (Mextech SL36, measurement range LP :30~130dB (A-weighted)) the average sound pressure level (re 20 μPa) of the Jerdon's courser call at a distance of 25m from the observer (PJ) was recorded as 71 dBA and the ambient sound was recorded as 51 dBA.

For the attenuation experiment, we used four types of commercial recorders - SongMeter4 (Wildlife Acoustics), Swift (Cornell Center for Conservation Bioacoustics), Rugged Swift (modified Swift in a Pelican casing), and AudioMoth (Open Acoustics) in a waterproof casing (AudioMoth for testing). All recorders had one functional omnidirectional microphone and were deployed simultaneously ~1.5m above the ground. The Jerdon's courser call was played using the FoxPro Predator speaker placed 1m above the ground (set to 20 points volume), oriented towards the recorders, at distances of 100m, 200m, 300m, 400m, 500m, 600m and 700m from the recorders. All recordings were then examined in the spectrogram format using Raven Pro (Supplementary Figure 1).
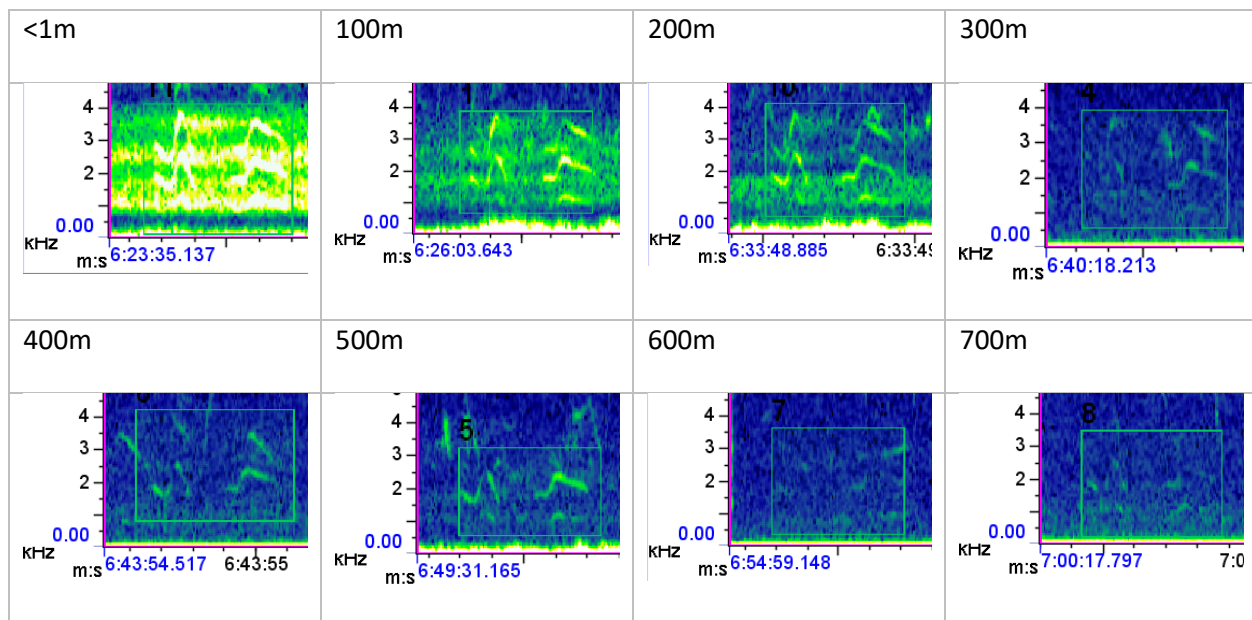
SUPPLEMENTARY FIG. 1 The panels represent the spectrogram view of the Jerdon's courser call (denoted within in green rectangles) recorded at various distances (<1 m, 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m) on the Rugged Swift recorder during the attenuation experiment.

SUPPLEMENTARY TABLE 1 Comparative details of the four recorder types used to detect Jerdon's courser.

Function	AudioMoth	SongMeter4	Swift	Rugged Swift
Configuration settings				
Cost	53 USD	849 USD	250 USD	300 USD
Sampling rate (kHz)	48	44.1	48	48
Gain	30.6dB (medium)	16dB (default)	33dB (default)	33dB (default)
File size	1 hour	1 hour	1 hour	1 hour
Battery (number x type)	3 x AA cell	4 x D-cell	3 x D-cell	12 x D-cell
Max SD Card capacity	128GB	256GB	256GB	256GB
Data collection				
Max detection distance for Jerdon's courser call	500m	700m[#]	700m[#]	700m
Average total data collected (Gigabytes /cycle	65.7 ± 2.19	121.63 ± 4.47	144.2 ± 1.3	238*
Average days run	12.4 ± 0.55	31.25 ± 0.70	34.6 ± 0.54	57*
Average hours run	182	406.25 ± 8.59	449.8 ± 6.63	741*

[#] Two recorders (SongMeter4 and Swift) did not record calls at 600 m and was faintly observed in our attenuation experiment to determine grid size (Supplementary Fig. 1) in the spectrogram of the Rugged recorder, this could be perhaps due to wind during the 600 m range of playback.

*The Rugged Swift card capacity of 256 GB was full by day 57, although the battery life was not exhausted. We would expect it to run for c. 80 days with a 512 GB memory card.

SUPPLEMENTARY MATERIAL 2 Jerdon's courser Quiz for experts to identify suspicious calls from our detections. This was presented to a team of 11 experts who are familiar with the birds of Sri Lankamaleshwara Wildlife Sanctuary and South India.

A team of researchers from IISER Tirupati and NCF deployed Automated Recording Units at SriLankamalleswara Wildlife Sanctuary between Oct 2019 and March 2020 to try and detect the Jerdon's courser (JC) through its call. We observed a few unusual vocalizations that fall withinthe Jerdon's courser calling band that we were unable to identify.

We would request you to please assess the following four calls below and provide us feedback on whether the call is more or less likely to belong to the Jerdon's courser. If not, then to pleaseidentify the species it belongs to.

For the unknown calls, a selection box has been drawn around the target call and only this is audible in the clip provided here. A buffer region around some target calls has been included to provide the context of the call. In the provided dynamic spectrograms, the green region denotesa strong acoustic signal whereas the blue region denotes a weak signal.

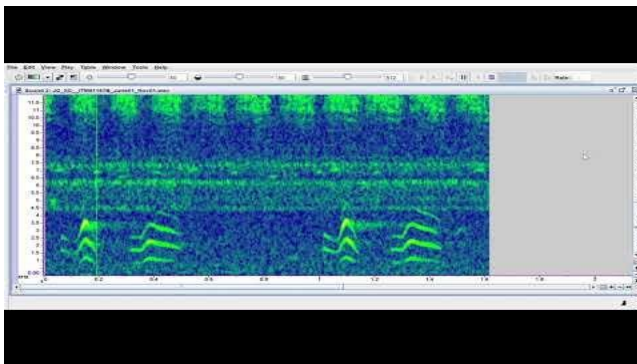Here is the original Jerdon's courser recording by P Jeganathan
https://www.xeno-canto.org/294415 (also provided below)

* Required

1. Email address *

    _____

Call of the Jerdon's courser for reference

http://youtube.com/watch?v=nduj9mbyTYs

Call 1 - 02/12/2019 - 23:43hrs

http://youtube.com/watch?v=epfrZyhTqdI
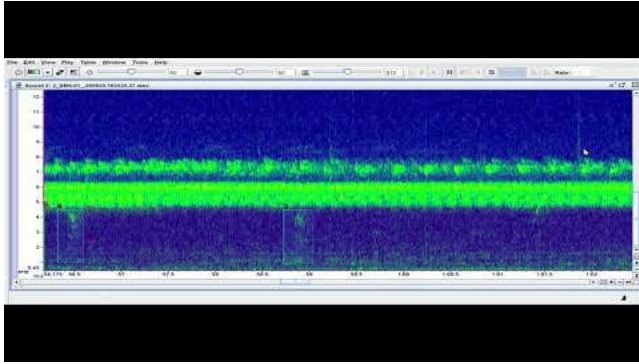
2. How likely do you think call 1 belongs to JC

Mark only one oval.

	1	2	3	4	5	
Highly unlikely	◯	◯	◯	◯	◯	Very likely

3. If not JC, call 1 belongs to which species?

Call 2 - 02/12/2019 - 23:59hrs

http://youtube.com/watch?v=ylw8GnmTKf4
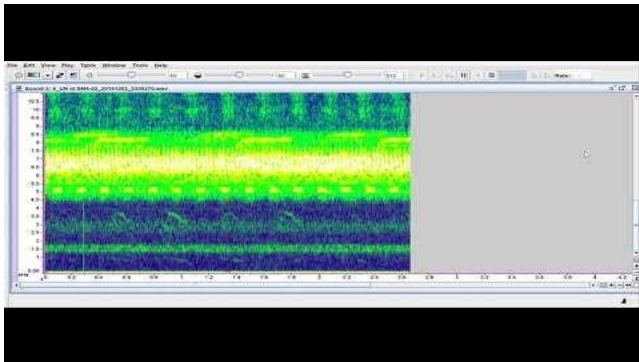
4. How likely do you think call 2 belongs to JC

Mark only one oval.

	1	2	3	4	5	
Highly unlikely	◯	◯	◯	◯	◯	Very likely

5. If not JC, call 2 belongs to which species?

_____

Call 3 - 17/11/2019 - 02:00hrs

http://youtube.com/watch?v=kMVOO7BIlms
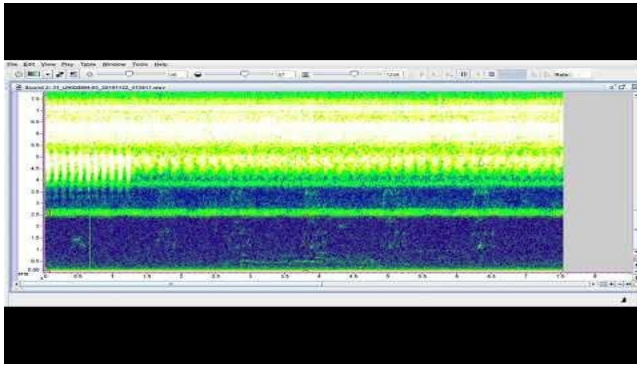
6. How likely do you think call 3 belongs to JC

Mark only one oval.

	1	2	3	4	5	
Highly unlikely	◯	◯	◯	◯	◯	Very likely

7. If not JC, call 3 belongs to which species?

_____

Call 4 - 04/12/2019 - 09:30hrs

http://youtube.com/watch?v=-1jE1-b30r4
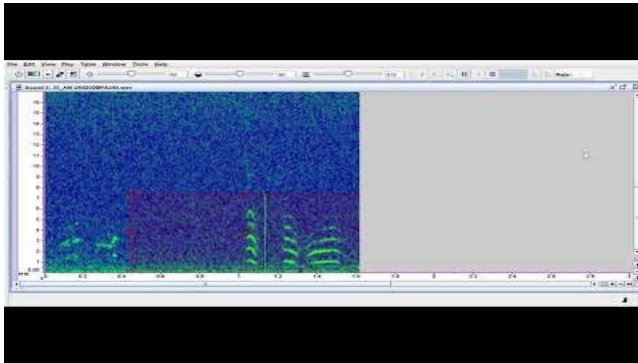
8. How likely do you think call 4 belongs to JC

Mark only one oval.

|	1	2	3	4	5	
Highly unlikely	◯	◯	◯	◯	◯	Very likely

9. If not JC, call 4 belongs to which species?

_____

SUPPLEMENTARY TABLE 2. Co-occurring bird species that vocalize within Jerdon's courser call band and picked up by the template detector in Raven Pro and Kaleidoscope.

| Sr. No	Species	Diurnal/nocturnal
1	Bay-backed Shrike *Lanius vittatus*	Diurnal
2	Black Drongo *Dicrurus macrocercus*	Diurnal
3	Common Hawk-Cuckoo *Hierococcyx varius*	Diurnal
4	Common Tailorbird *Orthotomus sutorius*	Diurnal
5	Grey Francolin *Francolinus pondicerianus*	Diurnal
6	Grey Junglefowl *Gallus sonneratii*	Diurnal
7	Grey-breasted Prinia *hodgsonii*	Diurnal
8	Indian Nightjar *Caprimulgus asiaticus*	Nocturnal
9	Indian Peafowl *Pavo cristatus*	Diurnal
10	Indian Thick-knee *Burhinus indicus*	Nocturnal
11	Jerdon's Nightjar *Caprimulgus atripennis*	Nocturnal
12	Jungle Nightjar *Caprimulgus indicus*	Nocturnal
13	Jungle Prinia *sylvatica*	Diurnal
14	Oriental Magpie-Robin *Copsychus saularis*	Diurnal
15	Pied Cuckoo *Clamator jacobinus*	Diurnal
16	Red-wattled Lapwing *Vanellus indicus*	Diurnal/nocturnal
17	Rose-ringed Parakeet *Psittacula krameri*	Diurnal
18	Savanna Nightjar *Caprimulgus affinis*	Nocturnal
17	Shikra *Accipiter badius*	Diurnal
20	Sirkeer Malkoha *Taccocua leschenaultii*	Diurnal
21	Streak-throated Woodpecker *Picus xanthopygaeus*	Diurnal
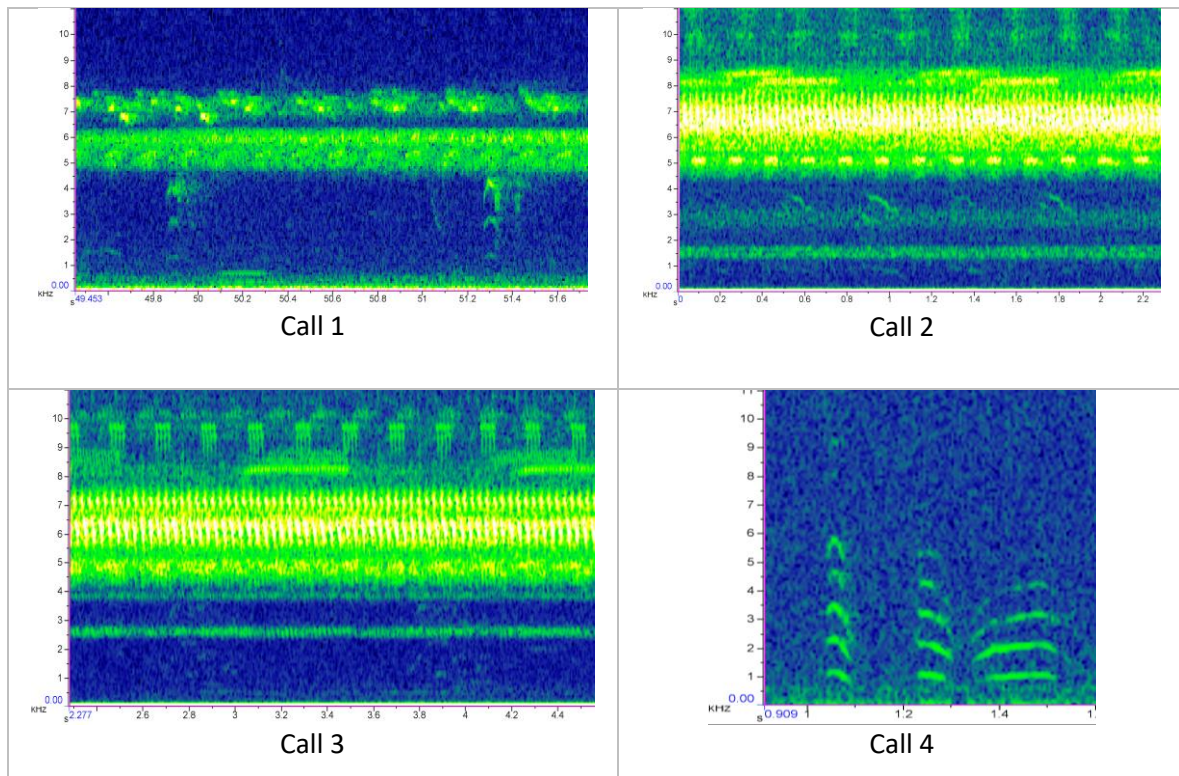
SUPPLEMENTARY FIG. 2 . Spectrograms of the four unknown calls identified by the template detector and sent for expert verification. Call 4 was considered most likely to be that of Jerdon's courser.
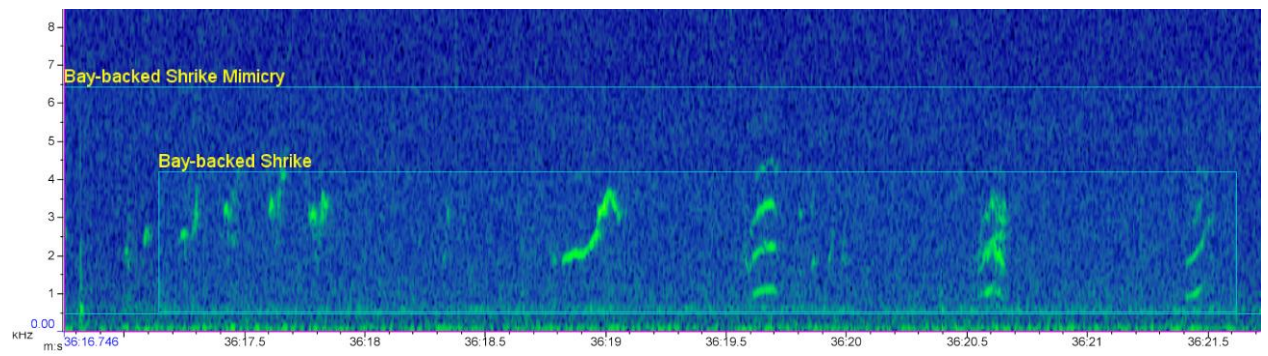
SUPPLEMENTARY TABLE 3 The values of the Spectral Cross-Correlation performed between the di-syllabic call of Jerdon's courser (JC) and the tri-syllabic putative call that was tagged by experts as most likely to belong to Jerdon's courser.
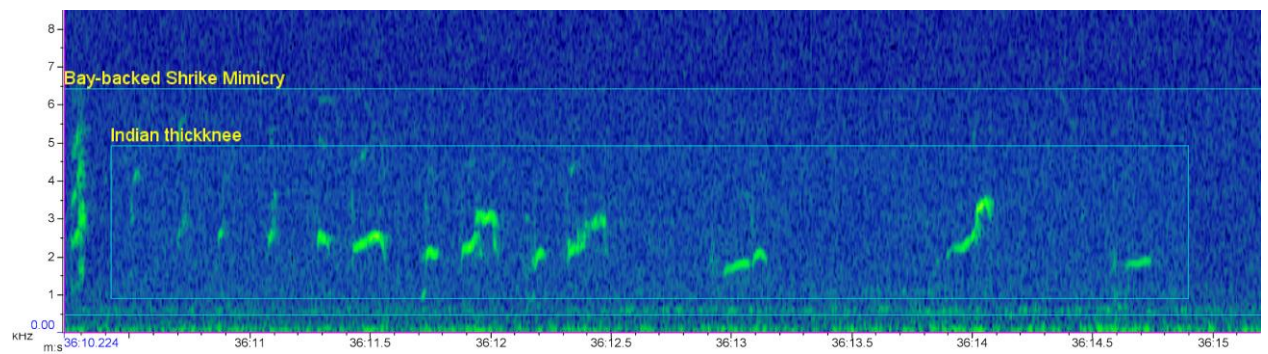
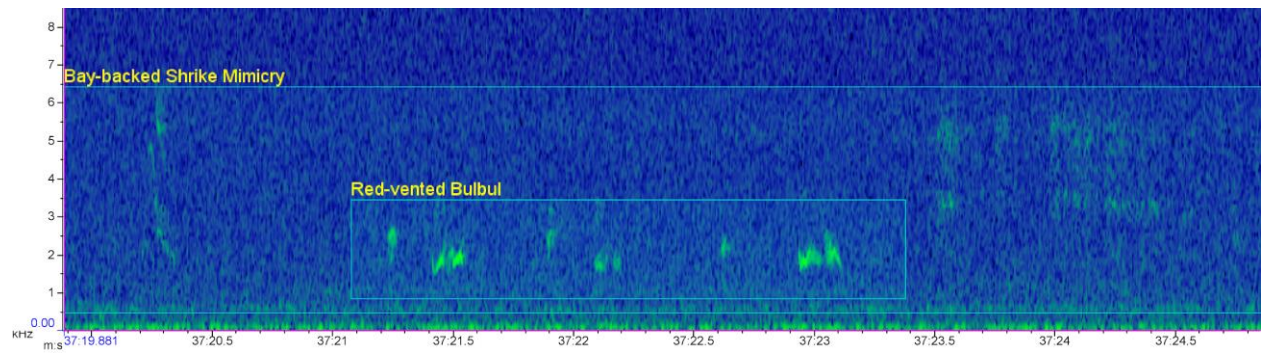|	JC_Note_1	JC_Note_2
Unknown Call4_Note1	0.591	0.402
Unknown Call4_Note2	0.504	0.454
Unknown Call4_Note3	0.383	0.534
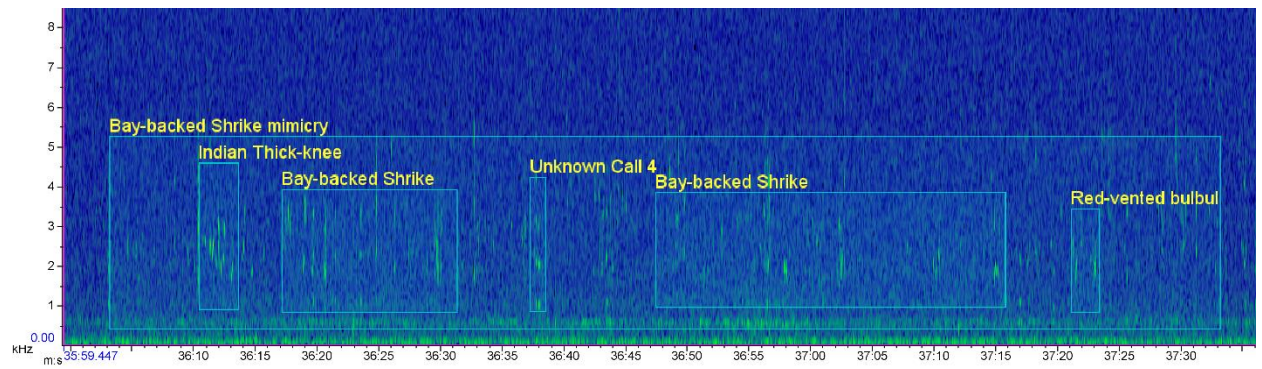
Panel 1

Panel 2

Panel 3

Panel 4

SUPPLEMENTARY FIG. 3 Spectrogram showing calls around the unknown call 4 (Panel 1). The spectrogram predominantly covers the calls of the bay-backed shrike (Panel 2) and includes calls of the Indian stone-curlew (Panel 3), unknown Call 4 and the red-vented bulbul (Panel 4). We suspect that the unknown call 4 might be a result of mimicry by the bay-backed shrike
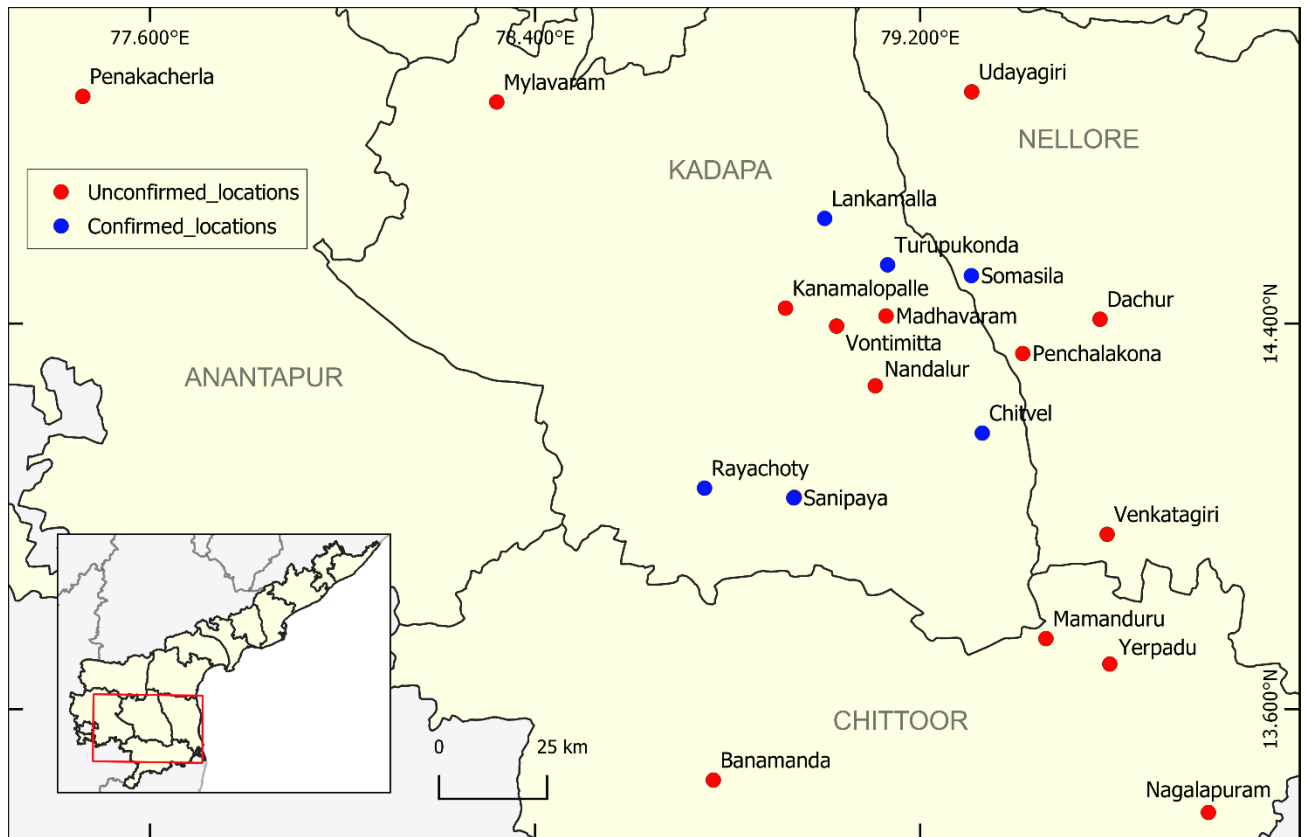
SUPPLEMENTARY FIG. 4 The inset map shows the district map of the state of Andhra Pradesh in India (in yellow). The main map shows the unconfirmed (red) and confirmed (blue) records of the Jerdon's courser from 1986–2000. Map based on Bhushan (1994) and Jeganathan, P. (2006).

a)

b)

c)

SUPPLEMENTARY FIG. 5 Inaccurate news stories indicating the discovery of the call of Jerdon's courser by our team in (a) The Hindu, 4 March 2020, (b) Saakshi (Telegu), 14 March 2020, and (c) The Hindu, 14 October 2020.

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